Hierarchical multi-scale model: from texture and substructure to evolution of plastic anisotropy and complex hardening

Jerzy Gawad[1,3], Philip Eyckens[2], Albert Van Bael[2], Dirk Roose[1], Paul Van Houtte[2]

[1]KU Leuven, Dept. Computer Science, Celestijnenlaan 200A, 3001 Heverlee, Belgium
[2]KU Leuven, Dept. Metallurgy and Materials Engineering, Kasteelpark Arenberg 44, 3001 Heverlee, Belgium
[3]AGH University of Science and Technology, Mickiewicza 30, Krakow, 30-059, Poland

In this study we investigate how to incorporate micro-scale physical phenomena into simulations on a much larger length scale, such as modelling of sheet metal forming operations. Two important micro-scale processes interact during the plastic deformation: evolution of the crystallographic texture and evolution of the substructure. The two not only influence activity of deformation mechanisms, but also result in macroscopically observable changes in both plastic anisotropy and hardening. Furthermore, they are involved in cross-effects, such as hardening of different slip systems, which becomes critically important if the macroscopic deformation path is changed. From the macroscopic mechanical point of view, the hardening evolves substantially faster than the plastic anisotropy. For this reason it is even not uncommon to assume constant plastic anisotropy in simulations of metal forming processes, but the strain hardening is usually considered inconstant.

In this paper we propose a decoupling scheme that exploits the two disparate evolution rates to accelerate the multi-scale model of multi-step plastic deformation. In essence, we adopt a strategy of approximating outputs of a fine scale model that are relevant for a coarse scale model. To capture the evolution of the homogenized variables, the coarse scale model makes use of computationally inexpensive and short-living analytical approximations, which are adaptively reconstructed at different frequency.

Both the coarse-scale plastic anisotropy and the hardening are derived from a fine scale crystal plasticity (CP) model by means of virtual experiments. The CP considers the development of the intragranular dislocation substructure as well as the evolution of texture under the constraint of nearest neighbor grain-to-grain interaction. The plastic anisotropy at the coarse scale level is modelled by means of a plastic potential function, while the hardening is approximated and extrapolated by low order polynomial interpolation functions. Although a number of virtual experiments have to be conducted to construct the plastic potential function, it can be exploited by the coarse scale model for a relatively large range of macroscopic strain. On the other hand, the hardening model has to be updated more frequently, but the computational cost of an update is considerably lower. Moreover, the hardening can be extrapolated along a recent strain path, and the events of strain path change can be easily captured to trigger a necessary reconstruction of the approximation. We show that the hierarchical model is able to accurately simulate multi-stage deformation processes. The investigated case study consists of equibiaxial stretching followed by uniaxial tension, Bauschinger test and a deep drawing process that involves three subsequent changes of the deformation path.